

CLAIMS

1. A method of calibrating downlink and uplink channels in a wireless multiple-input multiple-output (MIMO) communication system, comprising:

deriving a first transmit matrix based on a first pilot received via a MIMO channel between a transmitting entity and a receiving entity;

deriving a second transmit matrix based on a MIMO channel response estimate and first and second calibration error matrices, the MIMO channel response estimate being an estimate of a response of the MIMO channel and derived based on a second pilot received via the MIMO channel, the first calibration error matrix containing estimates of errors in a first correction matrix used to account for responses of transmit and receive chains at the transmitting entity, and the second calibration error matrix containing estimates of errors in a second correction matrix used to account for responses of transmit and receive chains at the receiving entity; and

revising the first and second calibration error matrices based on the first and second transmit matrices.

2. The method of claim 1, wherein the first pilot is a steered pilot received via a plurality of eigenmodes of the MIMO channel.

3. The method of claim 1, wherein the second pilot is a MIMO pilot comprised of a plurality of pilot transmissions sent from a plurality of transmit antennas at the transmitting entity, where the pilot transmission from each transmit antenna is identifiable by the receiving entity.

4. The method of claim 1, wherein the deriving a second transmit matrix comprises

decomposing the MIMO channel response estimate to obtain a first matrix of eigenvectors for the MIMO channel,

computing a second matrix of eigenvectors for the MIMO channel based on the MIMO channel response estimate and the first and second calibration error matrices, and

computing the second transmit matrix based on the second matrix of eigenvectors and the MIMO channel response estimate.

5. The method of claim 4, wherein the deriving a second transmit matrix further comprises

processing the second matrix of eigenvectors to obtain a third matrix of eigenvectors, wherein the processing on the second matrix matches processing performed by the transmitting entity to generate a transmit matrix based on a steered pilot received by the transmitting entity from the receiving entity, and wherein the second transmit matrix is computed based on the third matrix of eigenvectors and the MIMO channel response estimate.

6. The method of claim 5, wherein the processing the second matrix of eigenvectors comprises

performing orthogonalization on the eigenvectors in the second matrix to derive orthogonal eigenvectors for the third matrix.

7. The method of claim 1, wherein the first and second calibration error matrices are revised based on a minimum mean square error (MMSE) adaptive procedure.

8. The method of claim 1, wherein the revising the first and second calibration error matrices comprises

computing an error matrix as a difference between the first and second transmit matrices,

deriving partial derivatives for elements in the error matrix with respect to selected ones of elements in the first and second calibration error matrices,

computing an update vector based on the partial derivatives and the error matrix, and

updating the first and second calibration error matrices with the update vector.

9. The method of claim 8, wherein the deriving partial derivatives comprises

deriving a revised second transmit matrix based on the MIMO channel response estimate, the first and second calibration error matrices, and an error vector,

computing a revised error matrix as a difference between the first transmit matrix and the revised second transmit matrix, and

computing the partial derivatives based on the error matrix and the revised error matrix.

10. The method of claim 8, wherein the error matrix and the first and second calibration error matrices contain complex-valued elements, each complex-valued element having a real component and an imaginary component, and wherein the partial derivatives are derived separately for the real and imaginary components.

11. The method of claim 8, wherein the revising the first and second calibration error matrices further comprises

forming a matrix with the partial derivatives, and wherein the update vector is computed based on the error matrix and an inverse of the matrix of partial derivatives.

12. The method of claim 8, wherein the selected ones of the elements in the first and second calibration error matrices include all diagonal elements, except for upper leftmost elements, in the first and second calibration error matrices.

13. The method of claim 8, wherein the revising the first and second calibration error matrices further comprises

repeating the computing an error matrix, deriving partial derivatives, computing an update vector, and updating the first and second calibration error matrices for a plurality of times until the update vector satisfies a termination condition.

14. The method of claim 1, wherein the first and second calibration error matrices are revised based on a steepest descent adaptive procedure.

15. The method of claim 1, wherein the revising the first and second calibration error matrices comprises

computing an error matrix as a difference between the first and second transmit matrices,

computing an aggregate error based on the error matrix,

deriving partial derivatives for the aggregate error with respect to selected ones of elements in the first and second calibration error matrices, and

updating the first and second calibration error matrices with the partial derivatives.

16. The method of claim 15, wherein the aggregate error is computed as a sum of squares of magnitude of elements in the error matrix.

17. The method of claim 15, wherein the revising the first and second calibration error matrices further comprises

repeating the computing an error matrix, computing an aggregate error, deriving partial derivatives, and updating the first and second calibration error matrices for a plurality of times until the aggregate error satisfies a termination condition.

18. The method of claim 1, further comprising:

updating the second correction matrix with the second calibration error matrix.

19. The method of claim 1, wherein the first correction matrix is updated with the first calibration error matrix.

20. The method of claim 1, wherein the receiving entity is a user terminal and the transmitting entity is an access point in a time division duplex (TDD) MIMO system.

21. The method of claim 1, wherein the system utilizes orthogonal frequency division multiplexing (OFDM), and wherein a set of first and second calibration error matrices is derived for each of a plurality of subbands based on the first and second pilots received on the subband.

22. An apparatus in a wireless multiple-input multiple-output (MIMO) communication system, comprising:

a controller operative to

derive a first transmit matrix based on a first pilot received via a MIMO channel between a transmitting entity and a receiving entity,

derive a second transmit matrix based on a MIMO channel response estimate and first and second calibration error matrices, the MIMO channel response estimate being an estimate of a response of the MIMO channel and derived based on a second pilot received via the MIMO channel, the first calibration error matrix containing estimates of errors in a first correction matrix used to account for responses of transmit and receive chains at the transmitting entity, and the second calibration error matrix containing estimates of errors in a second correction matrix used to account for responses of transmit and receive chains at the receiving entity, and

revise the first and second calibration error matrices based on the first and second transmit matrices; and

a spatial processor operative to multiply data symbols with the second correction matrix prior to transmission via the MIMO channel.

23. The apparatus of claim 22, wherein the first pilot is a steered pilot received via a plurality of eigenmodes of the MIMO channel, and wherein the second pilot is a MIMO pilot comprised of a plurality of pilot transmissions sent from a plurality of transmit antennas at the transmitting entity, where the pilot transmission from each transmit antenna is identifiable by the receiving entity.

24. The apparatus of claim 22, wherein the controller is operative to revise the first and second calibration error matrices based on an adaptive procedure that iteratively adjusts the first and second calibration error matrices to reduce error between the first and second transmit matrices.

25. The apparatus of claim 22, wherein the controller is further operative to decompose the MIMO channel response estimate to obtain a first matrix of eigenvectors for the MIMO channel,

compute a second matrix of eigenvectors for the MIMO channel based on the MIMO channel response estimate and the first and second calibration error matrices, and

compute the second transmit matrix based on the second matrix of eigenvectors and the MIMO channel response estimate.

26. The apparatus of claim 22, wherein the controller is further operative to compute an error matrix as a difference between the first and second transmit matrices,

derive partial derivatives for elements in the error matrix with respect to selected ones of elements in the first and second calibration error matrices,

compute an update vector based on the partial derivatives and the error matrix,

update the first and second calibration error matrices with the update vector, and

repeat the computation of the error matrix, derivation of the partial derivatives, computation of the update vector, and updating of the first and second calibration error matrices for a plurality of times until the update vector satisfies a termination condition.

27. The apparatus of claim 22, wherein the controller is further operative to compute an error matrix as a difference between the first and second transmit matrices,

compute an aggregate error based on the error matrix,

derive partial derivatives for the aggregate error with respect to selected ones of elements in the first and second calibration error matrices,

update the first and second calibration error matrices with the partial derivatives, and

repeat the computation of the error matrix, computation of the aggregate error, derivation of the partial derivatives, and updating of the first and second calibration error matrices for a plurality of times until the aggregate error satisfies a termination condition.

28. An apparatus in a wireless multiple-input multiple-output (MIMO) communication system, comprising:

means for deriving a first transmit matrix based on a first pilot received via a MIMO channel between a transmitting entity and a receiving entity;

means for deriving a second transmit matrix based on a MIMO channel response estimate and first and second calibration error matrices, the MIMO channel response estimate being an estimate of a response of the MIMO channel and derived based on a second pilot received via the MIMO channel, the first calibration error matrix containing estimates of errors in a first correction matrix used to account for responses of transmit and receive chains at the transmitting entity, and the second calibration error matrix containing estimates of errors in a second correction matrix used to account for responses of transmit and receive chains at the receiving entity; and

means for revising the first and second calibration error matrices based on the first and second transmit matrices.

29. The apparatus of claim 28, wherein the first pilot is a steered pilot received via a plurality of eigenmodes of the MIMO channel, and wherein the second pilot is a MIMO pilot comprised of a plurality of pilot transmissions sent from a plurality of transmit antennas at the transmitting entity, where the pilot transmission from each transmit antenna is identifiable by the receiving entity.

30. The apparatus of claim 28, further comprising:

means for decomposing the MIMO channel response estimate to obtain a first matrix of eigenvectors for the MIMO channel;

means for computing a second matrix of eigenvectors for the MIMO channel based on the MIMO channel response estimate and the first and second calibration error matrices; and

means for computing the second transmit matrix based on the second matrix of eigenvectors and the MIMO channel response estimate.

31. The apparatus of claim 28, further comprising:

means for computing an error matrix as a difference between the first and second transmit matrices;

means for deriving partial derivatives for elements in the error matrix with respect to selected ones of elements in the first and second calibration error matrices;

means for computing an update vector based on the partial derivatives and the error matrix;

means for updating the first and second calibration error matrices with the update vector; and

means for repeating the computation of the error matrix, derivation of the partial derivatives, computation of the update vector, and updating of the first and second calibration error matrices for a plurality of times until the update vector satisfies a termination condition.

32. The apparatus of claim 28, further comprising:

means for computing an error matrix as a difference between the first and second transmit matrices;

means for computing an aggregate error based on the error matrix;

means for deriving partial derivatives for the aggregate error with respect to selected ones of elements in the first and second calibration error matrices;

means for updating the first and second calibration error matrices with the partial derivatives; and

means for repeating the computation of the error matrix, computation of the aggregate error, derivation of the partial derivatives, and updating of the first and second calibration error matrices for a plurality of times until the aggregate error satisfies a termination condition.

33. A method of calibrating downlink and uplink channels in a wireless multiple-input multiple-output (MIMO) communication system, comprising:

performing a first calibration based on downlink and uplink channel response estimates for a MIMO channel between a transmitting entity and a receiving entity to obtain first and second correction matrices, the first correction matrix being used to account for responses of transmit and receive chains at the transmitting entity and the second correction matrix being used to account for responses of transmit and receive chains at the receiving entity; and

performing a second calibration based on first and second pilots received via the MIMO channel to obtain first and second calibration error matrices, the first calibration

error matrix containing estimates of errors in the first correction matrix and the second calibration error matrix containing estimates of errors in the second correction matrix.

34. The method of claim 33, further comprising:
updating the second correction matrix with the second calibration error matrix.

35. The method of claim 33, wherein the first pilot is a steered pilot received via a plurality of eigenmodes of the MIMO channel, and wherein the second pilot is a MIMO pilot comprised of a plurality of pilot transmissions sent from a plurality of transmit antennas at the transmitting entity, where the pilot transmission from each transmit antenna is identifiable by the receiving entity.

36. The method of claim 33, wherein the performing a second calibration comprises
deriving a first transmit matrix based on the first pilot,
deriving a second transmit matrix based on a MIMO channel response estimate obtained from the second pilot, and
revising the first and second calibration error matrices based on the first and second transmit matrices.

37. The method of claim 36, wherein the first and second calibration error matrices are revised using an adaptive procedure that iteratively adjusts the first and second calibration error matrices to reduce error between the first and second transmit matrices.

38. An apparatus in a wireless multiple-input multiple-output (MIMO) communication system, comprising:
a controller operative to
perform a first calibration based on downlink and uplink channel response estimates for a MIMO channel between a transmitting entity and a receiving entity to obtain first and second correction matrices, the first correction matrix being used to account for responses of transmit and receive chains at the transmitting entity

and the second correction matrix being used to account for responses of transmit and receive chains at the receiving entity, and

perform a second calibration based on first and second pilots received via the MIMO channel to obtain first and second calibration error matrices, the first calibration error matrix containing estimates of errors in the first correction matrix and the second calibration error matrix containing estimates of errors in the second correction matrix; and

a spatial processor operative to multiply data symbols with the second correction matrix prior to transmission via the MIMO channel.

39. The apparatus of claim 38, wherein the controller is operative to
derive a first transmit matrix based on the first pilot,
derive a second transmit matrix based on a MIMO channel response estimate obtained from the second pilot, and
revise the first and second calibration error matrices based on the first and second transmit matrices.

40. The apparatus of claim 39, wherein the controller is operative to revise the first and second calibration error matrices using an adaptive procedure that iteratively adjusts the first and second calibration error matrices to reduce error between the first and second transmit matrices.

41. An apparatus in a wireless multiple-input multiple-output (MIMO) communication system, comprising:

means for performing a first calibration based on downlink and uplink channel response estimates for a MIMO channel between a transmitting entity and a receiving entity to obtain first and second correction matrices, the first correction matrix being used to account for responses of transmit and receive chains at the transmitting entity and the second correction matrix being used to account for responses of transmit and receive chains at the receiving entity; and

means for performing a second calibration based on first and second pilots received via the MIMO channel to obtain first and second calibration error matrices, the first calibration error matrix containing estimates of errors in the first correction matrix

and the second calibration error matrix containing estimates of errors in the second correction matrix.

42. The apparatus of claim 41, wherein the means for performing a second calibration comprises

means for deriving a first transmit matrix based on the first pilot,

means for deriving a second transmit matrix based on a MIMO channel response estimate obtained from the second pilot, and

means for revising the first and second calibration error matrices based on the first and second transmit matrices.

43. The apparatus of claim 42, wherein the first and second calibration error matrices are revised using an adaptive procedure that iteratively adjusts the first and second calibration error matrices to reduce error between the first and second transmit matrices.